Improving Polarization Measurement Methods

Arianna Moshary and Christopher Bussetti

Project Goals

-Collect and analyze data using current devices.
-Design and use an advanced polarimeter using digital camera technology.

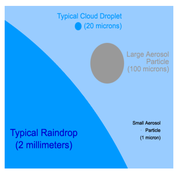
Abstract

The aerosols in the atmosphere have an important yet poorly understood effect on human lives. NASA has studied greenhouse gases and their effect on the environment in depth, but NASA is only fairly recently beginning to study and understand aerosols. This coming January, NASA will launch the GLORY mission, a satellite which will collect data on the aerosols in the environment partly by use of a polarimeter. While this data will be extremely valuable, it is also important to collect data at ground level to compare to the data collected from orbit. Thus, this team has been working on developing accurate and effective polarimeters to use from Earth.

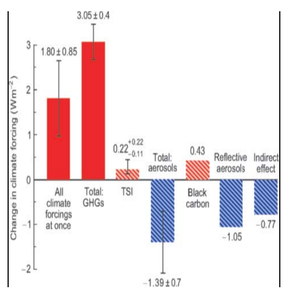
In our project last year, we were able to build a solar cell polarimeter that could measure polarization and allowed us to generate DOLP graphs. However, the data we collected was not very accurate and the equipment we were using was bulky and inefficient. This year's project focuses on the use of newer technology to better measure aerosols, the digital camera. Using a high-tech SLR and polarizing filter, we were able to collect our data and then process it using both Adobe Photoshop and a computer program written in IDL which we are still perfecting.

An Introduction to Aerosols

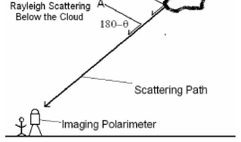
•Aerosols are tiny liquid or solid (not gas) particles (0.001 to 100 μm) suspended in the air.
•Some occur naturally, but humans activities are responsible for roughly 10% of all aerosols.



•Direct Effect on Climate:
Aerosols in the atmosphere have a direct effect the climate. As incoming sunlight enters the atmosphere, it is either absorbed or reflected by aerosol particles, causing a warming and a cooling effect respectively.



•Indirect Effect on Climate:
Aerosols also have an indirect cooling effect on the climate by changing cloud composition.
NASA's GLORY Mission (launch this coming January) seeks to learn more about the aerosol content of the atmosphere and its effects



Key Concepts: Polarized Light and DOLP

- **Natural light (sunlight) is made up of waves with electromagnetic fields vibrating in all directions**
- **Polarized light has the electromagnetic fields moving in the same direction.**
- **As sunlight enters the atmosphere and hits aerosols, it is partially polarized.**
- **This partial polarization is dependent on aerosol size, composition, and concentration.**
- **The degree of linear polarization (DOLP) is a measure of this polarization.**
- **The graph of DOLP against scattering angle ideally produces a bell curve with its peak at 90 degrees.**

Calculating DOLP:

$$P_T = \frac{(Q^2 + U^2 + V^2)^{1/2}}{I} \longleftrightarrow P = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

General Equation to Calculate Polarization (Uses measurements from 4 angles)

Simplified Equation (Uses measurements from two angles, max and min in this case)

To calculate DOLP, we used this simplified version of the general equation. Two directions of polarization are required for use of this equation, and we used the angles max and min polarization, which are separated by 90 degrees.

Solar Cell Polarimeter

•Uses the principles of polarized light and knowledge of light's path through the atmosphere (Mie Scattering of larger particles and Rayleigh Scattering from smaller ones)
•Steps:
-Light enters the polarimeter tube and passes through a polarizer.
-Polarized light filtered by infrared cutoff and color lens to limit wavelength.
-Lens focuses light onto solar cell which translates the light to electricity to be measured by multimeter
-Polarimeter is rotated to collect the amount of polarized light at the min and max directions of polarization and is positioned at different angles from the sun.
-When collected data is used in conjunction with a sun-photometer (to measure optical thickness), particle size and index of refraction can be determined.

Digital Camera Polarimeter

PRINCIPLES:

•Captures and stores photographs of the sky.

•These photographs contain data on the intensity of light coming from the given direction.

•This intensity measure can be retrieved for each color by looking at the red, green, and blue pixel counts.

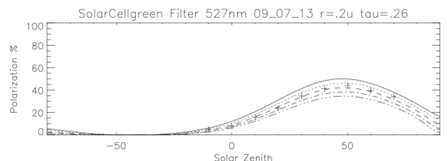
•The maximum and minimum intensities by direction can be determined by the calibrated circular polarization filter.

The Camera (Nikon D60)

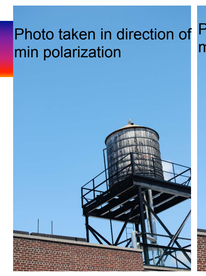
The Tripod (to change the scattering angle measured)

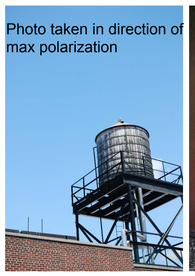
The "Circular Polarization Filter"
•Not really a circular polarization filter, because there is no such thing.
•Is actually a linear polarizer with a quarter wave plate on the back surface.
•Linearly filters the light and then converts it into circularly polarized light.)

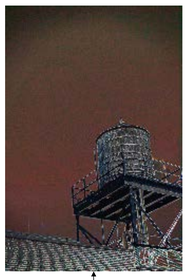
Data and Photographs



This is a graph of DOLP against angle. The +'s are the data points we measured and calculated using the solar cell polarimeter.







These two images are then processed with Adobe Photoshop to generate the polarization picture shown here:

Shown here are two more polarization images processed by Adobe Photoshop.

Conclusion and Future Work

In this project, we accomplished both of our two initial goals. We tested for accuracy and then used the solar cell polarimeter that we built last year. With this data, we were able to create several graphs and through comparison to known models, we concluded that the particles in our area (by the NASA GISS building) are approximately 0.2 microns in radius with an index of refraction of 1.45.

We also began work on the digital camera polarimeter. We created a design, selected the necessary parts, calibrated the instrument, and then began taking photographic data with the instrument. The photographs above show the data as we processed it with Adobe Photoshop. We layered the two photos from the min and the max and then subtracted the pixels to generate these images. The images do not show the DOLP, but give an initial sense of polarization from using half of the DOLP ratio. Our initial work with the camera polarimeter shows promise because the images have some crucial parts accurate. For example, the clouds in the processed photos appear black or very dark, which indicates that there is no difference between the two images at those points. This makes sense because light that is scattered by clouds is unpolarized. In contrast the sky is lighter, which occurs because the light scattered by clear sky is polarized.

There is still some work that we would like to accomplish on this project. The next step in this project would be to create images showing the DOLP ratio and use those to generate graphable, numerical data. Furthermore, we began work on a IDL program to process these images, but the program still has bugs and slight storage issue to be fixed. We would also like to find a way to better account for photograph shifts. For each polarization image to be generated, two photos must be taken, one min and one max. Often there is a slight time shift and an angle shift between these photos so that when they are layered to be differenced, they don't match up exactly. This results in the light rings around clouds and buildings. We were able to use Photoshop to fix this problem to a degree, but for more accurate data analysis, we would need to examine the error associated with each of these shifts in the photos.

Sponsors:
National Aeronautics and Space Administration (NASA)
NASA Goddard Space Flight Center (GSFC)
NASA Goddard Institute for Space Studies (GISS)
NASA New York City Research Initiative (NYCRI)

Contributors:
Dr. Barbara Carlson (PI)
Dr. Brian Cairns (PI)
Dr. James Frost (PI)
Natalie Williams (High School Teacher)
Christopher Bussetti (Undergraduate Student)
Arianna Moshary (High School Student)